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Research Paper

Enhancing Productivity of Bread Wheat (*Triticum aestivum L.)* Through Integrating Vermicompost and N fertilizer in Meskan, Central Ethiopia

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Abstract

Soil fertility management is very crucial to optimize and sustain agricultural production to secure food for the current generation as well as the generation to come. Ethiopia is striving to secure food by optimizing and sustaining crop production. The purpose of the study was to examine the combined effect of organic (vermicompost) and inorganic (nitrogen) fertilizer rates on the growth and yield of bread wheat in Meskan district, Central Ethiopia. The experiment used four levels of vermicompost (0, 1, 1.5, and 2 t ha-1) and Nitrogen (0, 50, 75, and 100 kg ha-1) in a factorial combination in RCBD design with three replications using a wheat variety (Kekeba) as the test crop. The result of the study asserted that yield and yield-related traits were significantly different across the treatment combinations at $P < 0.05$. The treatment of 2 t ha-1 vermicompost + 75 kg ha-1 of N produced the highest grain yield (2.773 t ha-1); while the control treatment had the lowest grain yield (1.062 t ha-1). Hence, a combined application of vermicompost and N fertilizer optimize wheat production in the study area compared to the sole application of vermicompost or N fertilizers. Therefore, the combined application of organic and inorganic fertilizers could have a great contribution towards food security for countries like Ethiopia with low fertilizer input users and high food insecurity levels.

1. Introduction

Land degradation associated with soil fertility depletion is a serious global problem that affects agricultural productivity and leads to food insecurity. Agricultural practices in an unjustifiable manner, limited resources and underuse of nutrients in most Sub-Saharan Africa (SSA) countries have resulted in serious depletion of soil nutrients, and low crop yields that led to poverty and food insecurity (FAO, 2022). Land degradation is seriously affecting the agricultural productivity of Ethiopia, where more than 85% of the economy is dependent on agriculture. Soil degradation has resulted in drought, ecological imbalance and consequent degradation of the quality of life (Merkineh, 2017). The livelihood of the rural people of Ethiopia is seriously threatened by land

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degradation (Kassahun and Yitbarek, 2018; Belay, 2024). The decreasing fertility of soils is considered a major cause of reduced crop yields and per capita food production in Africa (Zewdie, 2022).

Crop growth, development and production are dependent on essential plant nutrients that are found in minerals and organic soils. The status of those essential nutrients varies in the soil due to many factors such as parent materials (both organic and inorganic sources), climate, organisms, relief, cultivation, soil conservation and management. Not all soils have the same potential to provide essential nutrients (FAO, 2022). In some areas, soils are naturally infertile with little or no agricultural production; in other areas, soil degradation has reduced soil fertility. In both scenarios, crop growth, development and production could be affected. Therefore, to optimize and sustain the fertility of a given soil for optimum and sustainable crop production, the appropriate addition of fertilizers (organic and inorganic sources) is mandatory.

Bread wheat (*Triticum aestivum L.)* is one of the most important staple crops in Ethiopia. Ethiopia is Africa's second-largest wheat producer next to Egypt which accounts for roughly 20% of total African wheat production (Mamo & Habtamu, 2022). The country did not attain the full potential of wheat production mainly due to poor soil management (Markam, 2021). Considering inorganic fertilizers (Nitrogen and Phosphorus) use, Ethiopia on average used 31.1 kg/ha for the year 2020, which was by far less than from world average (129 kg/ha) and Ireland (412.3 kg/ha) (FAO, 2022). In the same year data, the food insecurity level of Ethiopia was 56.3%. For low fertilizers input users like Ethiopia, integrated use of organic and inorganic fertilizers would have paramount importance in improving soil fertility for optimum and sustainable crop production. Integrating organic fertilizers like vermicompost would improve the soil's physical and biological condition, besides the chemicals. The Ethiopian government has a special focus on increasing the production of wheat across the country. This will be realized by improving the soil fertility status through the application of both organic and inorganic fertilizers.

Wheat highly demands nitrogen for vigorous growth, development and optimum production as compared to other macronutrients. The cropland nitrogen budget of Ethiopia for the year 2020 was 16.3 kg/ha (FAO, 2022), which was by far less than the world average (54.4 kg/ha) and Bahrain (620.3 kg/ha). Nitrogen availability influences crop development throughout the crop cycle, influencing seedling establishment, tillering, quantity of grains per spike, canopy development, and grain filling (Negessa and Abdisa, 2021). Nitrogen efficient management is basic to optimize its utilization while decreasing pollution (Pržulj and Momčilović, 2001). Excess N application rates create acidity and make the soil more vulnerable to other biotic and abiotic impacts. As a result, applying nitrogen fertilizer at the correct rate is crucial for increasing soil fertility and crop yield (Getachew et al., 2014).

Vermicompost has macro and micro-nutrients, vitamins, growth hormones, and enzymes such as proteases, amylases, lipase, cellulase and chitinase (Rehman et al., 2023). It enhances the physical, chemical and biological properties of soil that optimize and sustain crop production. Vermicompost protects crops from biotic and abiotic stresses without harming the environment (Al-Maamori et al., 2023). It also increases the use efficiency of inorganic fertilizers (Blouin et al., 2019). Generally, vermicompost improves plant growth, development, yield and quality (Hawkesford, 2014; Prajapati et al., 2023).

Organic fertilizers, such as vermicompost, used in conjunction with inorganic fertilizers have the potential to boost and sustain crop yields while preserving soil fertility. When compared to the use of the sole application of inorganic fertilizers, the combined application of organic and inorganic fertilizers enhanced crop yield (Getachew & Chun, 2017). Integrated soil fertility management is crucial for restoring soil fertility and boosting plant nutrient availability to optimize crop growth and production (Getachew & Chun, 2017). Inorganic fertilizers have been used by the farmers of the study area; however, currently integrating with organic fertilizer is advocated by government and non-governmental organizations. However, their rates of application and integrative response for bread wheat variety have not been studied in the study area. As a result, the purpose of this study was to investigate the combined effect of vermicompost and nitrogen fertilizer on the growth and yield of bread wheat variety in the Meskan district, Central Ethiopia.

2. Materials and Methods

2.1. Description of the Study Area

The experiment was conducted in Meskan district, Central Ethiopia in the 2020 cropping season under rain-fed conditions. Geographically, it is located at latitude of 7°.99′35″–8°02′781″N and longitude of 38°.26′31′–38°.57′86″E. The long-term mean annual rainfall of the study area ranges between 1001-1200 mm. Its elevation ranges from 1501-3500 m a.s.l (MWAO, 2020). The major soil colors include 22% red, 25% brown and 53% black. Its elevation ranges from 1501-3500 m above sea level (Meskan Woreda Agricultural Office -MWAO, 2020).

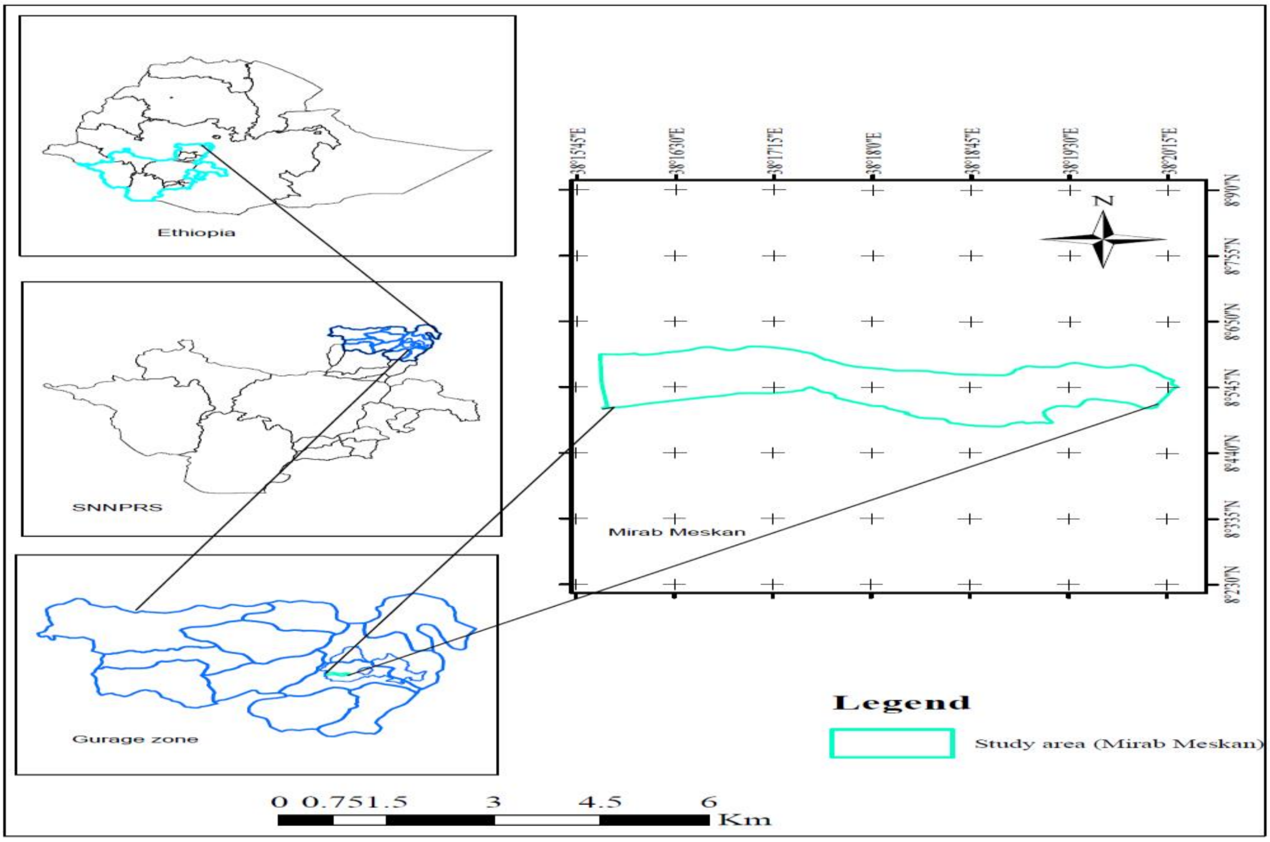

Figure 1: Map of the Study Area (West Meskan Kebele)

The district is classified into Dega (2300-3200 m a.s.l) and Waina Dega (1500 - 2300 m a.s.l) agro-ecological zone. According to MWAO (2020), the study area is characterized by a monomodal rainfall pattern with peaks in July and August and a monthly average of 84.00 mm (Figure 2). About 80% of the rainfall falls in the main rainy season *"Kiremt'*, starting from June and extending to September. The mean monthly minimum and maximum air temperature of the study area were 10.27 and 24°C, respectively (MWAO, 2020).

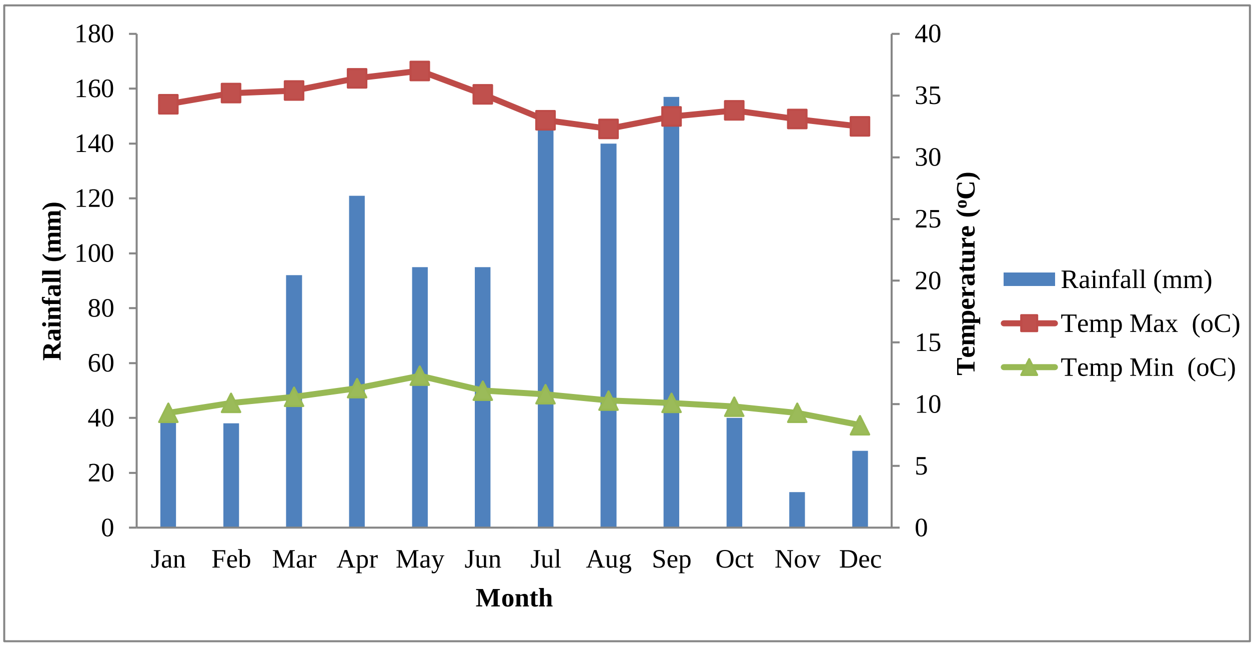

Figure 2: Mean monthly maximum, minimum temperature and rainfall of the study area

2.2. Treatments and Experimental Design

Bread wheat recently released variety (*Kekeba*) was used for the experiment as a test crop. Fertilizers used for the study were N in the form of urea [CO $(NH2)_2$] (46% N) at different rates and phosphorus in the form of triple superphosphate (TSP) (46% P2O5) at an equal rate for all plots. This experiment used the recommended N fertilizer 100 kg ha -1 urea as stated by (MoA, 2016). This experiment used the recommended N fertilizer 100 kg ha -1 urea as stated by (MoA, 2016).

Table 1: Treatment combination in factorial arrangement

Treatment	Fertilizer combinations'
1	0 kg ha^{-1} urea + 0 ton ha^{-1} vermicompost
2	0 kg ha^{-1} urea + 1 ton ha^{-1} vermicompost
3	0 kg ha^{-1} urea + 1.5 ton ha^{-1} vermicompost
4	0 kg ha^{-1} urea + 2 ton ha^{-1} vermicompost
5	50 kg ha^{-1} urea + 0 ton ha^{-1} vermicompost
6	50 kg ha^{-1} urea + 1 ton ha^{-1} vermicompost
7	50 kg ha^{-1} urea+ 1.5 ton ha^{-1} vermicompost
8	50 kg ha^{-1} urea + 2 ton ha^{-1} vermicompost
9	75 kg ha^{-1} urea + 0 ton ha^{-1} vermicompost
10	75 kg ha^{-1} urea + 1 ton ha^{-1} vermicompost
11	75 kg ha^{-1}urea + 1.5 ton ha^{-1} vermicompost
12	75 kg ha^{-1}urea + 2 ton ha^{-1} vermicompost
13	100 kg ha^{-1}urea + 0 ton ha^{-1} vermicompost
14	100 kg ha^{-1}urea + 1 ton ha^{-1} vermicompost
15	100 kg ha^{-1}urea + 1.5 ton ha^{-1} vermicompost
16	100 kg ha^{-1}urea + 2 ton ha^{-1} vermicompost

The treatments include four levels of nitrogen fertilizer rates in the form of urea (0, 50, 75 and 100 kg ha-1) and four levels of Vermicompost (0, 1, 1.5 t ha-1 and 2 t ha-1) as depicted in Table 1. The experiment was arranged in a 4 x 4 factorial and laid on RCB design with three replications having sixteen treatment combinations.

2.3. Experimental Procedures

The field was plowed and harrowed by oxen to get a fine seed bed and level manually before the field layout was made. Field layout was made and each treatment was assigned randomly to the experimental units with three replications that the spacing between the block and within the plot of 1 meter and 0.5 meter, respectively. The gross plot size for planting was 3 m × 2 m (6 m^2) accommodating 10 rows spaced 0.2 m apart. The wheat seed was sown by drilling in rows at the recommended rate of 150 kg ha^{-1} (MoA, 2012). Accordingly, 75 gm seeds were sown per plot. Eight central rows with a net plot area (4.8 m^2) were used for data collection and measurement for plot base parameters while five plants were used for measurement of sampling parameters. Standard agronomic management practices (cultivation, weeding and other pest and disease management) activities were applied to all plots uniformly. No insecticide or fungicide was applied since there was no outbreak of insects or diseases. Harvesting was done manually using hand sickle. Phosphorus fertilizer at the recommended rate of 46 kg P_2O_5 ha^{-1} in the form of TSP was applied equally to all plots by surface broadcasting and mixing with the soil at sowing.

2.4. Data Collection

2.4.1. Soil Sampling and Analysis

Composite soil samples were taken from the upper 0-30 cm of the experimental site using the zigzag sampling pattern using Auger to collect a representative soil sample of the plot before planting. The samples were air-dried, and ground using a pestle and a mortar, and it was allowed to pass through a 2 mm sieve. The samples were analyzed at Wolkite Soil Laboratory for selected physicochemical properties. Soil OC was determined by the wet oxidation method (Walkley & Black, 1934). The total N in the soil samples was analyzed using the Kjeldahl method (Bremner & Mulvaney, 1981). Available P was determined using the Olsen extraction method (Van Reeuwijk, 2002). Cation exchange capacity (CEC) was determined following the ammonium acetate (1N NH_4OAc) extract method (Van Reeuwijk, 2002).

2.4.2. Growth Parameters

Plant height (cm): It was measured by a meter tape from the ground level to the tip of the main stem at physiological maturity from 5 randomly selected plants from each plot.

Spike length (cm): It was measured by a meter tape from five randomly selected plants for each plot and their average was taken as a representative of the respective treatment.

2.4.3. Yield and Yield Components

Number of Productive Tiller (NT): The number of productive tillers was counted from the five sample plants from each plot.

Above-ground biomass yield (ton ha⁻¹): Above-ground biomass yield was measured by weighing the sun-dry total above-ground plant biomass (straw + grain) of the net plot and converted to ton per hectare.

Grain yield (kg ha^{-1}): The grain yield was measured by taking the weight of the grains from the net plot area and converted to Kg per hectare after adjusting the grain moisture content to 12.5%. Adjusted grain yield (kg ha^{-1}) = yield obtained $\{\text{Kg ha}^{-1}\text{X}\frac{(100-\%\text{MC})}{(100-\%\text{Mc})}\}$ MC=Measure grain moisture content (%) and Mc=the standard moisture content (12.5%). Grain moisture content was determined by using a seed moisture tester instrument.

2.5. Data Analysis

The data were subjected to Analysis of Variance (ANOVA) following a GLM procedure using SAS software version 9.4. The means comparison was performed using the LSD test at $P < 0.05$ significant level for wheat growth parameters, yield and yield components.

3. Results and Discussion

3.1. Soil Characteristics of the Study Site

The total N and OC contents of the soils before planting were 0.18 and 2.14%, respectively. The soil OC and total N contents of the soils were rated as moderate (Tekalign et al., 1991). The available P content of the soils was 9.8 mg kg^{-1} and rated as medium (Olsen et al., 1954). While the high (32 cmol(+) kg^{-1}) CEC value of the soils was recorded at the study site. However, the vermicompost was characterized by high contents of OC (4.87 %), total N (0.42%) and CEC43 cmol(+) kg^{-1} value, but with low (4.2 mg kg^{-1}) available P.

3.2. Effect of Combined N and Vermicompost Fertilizers on Growth Parameters of Wheat Crop

3.2.1. Plant Height

The result of the analysis of variance showed that plant height was highly significantly ($P < 0.05$) influenced by the interaction effects of nitrogen and vermicompost fertilizers (Appendix Table 1). The tallest (120 cm) plant height was recorded at the combined rate of 100% N and 1 t ha^{-1} of vermicompost fertilizers followed by 118 cm at the same rate of N 118 cm and 1.5 t ha^{-1} whereas the unfertilized plots had the shortest (67.1 cm) plant height (Table 2).

The result of the study asserted that sole application of inorganic N fertilizer and vermicompost as well as their combination at different rates could increase plant height significantly as compared to the control. The tallest plant height observed with the combined application of inorganic N fertilizer and vermicompost suggests that the efficiency of inorganic N fertilizer may be improved when used in conjunction with vermicompost.

Table 2: Plant height of bread wheat influenced by the interaction effects of different levels of Nitrogen and Vermicompost

N levels (Kg ha^{-1})	Vermicompost (t ha^{-1}) 0	1	1.5	2
0	67.1^{hg}	70.1^{hg}	71.8^{fg}	76.5^{cde}
50	76.7^{cde}	76.7^{cde}	81.4^{bcd}	82.0^{b}
75	78.1^{bcde}	77.4^{cde}	79.2^{bcde}	116^{ab}
100	118^{ab}	120^{a}	118^{ab}	117^{ab}
LSD (5%)	6.0			
CV (%)	3.24			

Means within a column followed by the same letter are not significantly different at ($P \leq 0.05$); LSD: least significant difference; CV: coefficient of variation.

Several studies, including those by Fayera and Mohammed (2014), Sutharsan and Rajendran (2016), and Melesse (2017), have demonstrated that the combined application of inorganic nitrogen fertilizer and vermicompost enhances plant growth parameters, such as increasing plant height. The increase in the rates of N and vermicompost fertilizers increased plant height indicated the synergetic effect of fertilizer on the plant height of bread wheat. For instance, in a combined application of inorganic and organic fertilizers plant height increased with increasing nitrogen rate.

3.2.2. Spike Length

The results showed that there were highly significant (P < 0.001) differences in spike length due to nitrogen, vermicompost and their interaction effect (Appendix Table 1). The largest (9.0 cm) spike length was observed with a combined application of 1 t ha^{-1} vermicompost and 100 kg N ha^{-1} (Table 3), whereas the lowest (7.1 cm) spike length was obtained from the control plot. However, no consistent increase in spike height was observed across all increasing doses of the fertilizers. In general, high photosynthetic efficiency and high dry matter accumulation could enhance spike length and grain production due to the use of balanced fertilizer and the utilization of nutrient efficiently (Belete *et al*., 2018).

Table 3: Spike length of Bread wheat influenced by the interaction effects of different levels of Nitrogen and Vermicompost

N levels (Kg ha^{-1})	**Vermicompost (t ha^{-1})** 0	1	1.5	2
0	7.1^{e}	7.5^{cde}	7.2^{de}	7.6^{bc}
50	7.9^{bc}	7.7^{bc}	7.5^{bcd}	7.5^{bcd}
75	7.8^{bc}	8.9^{a}	7.6^{bc}	7.5^{bcd}
100	7.6^{bc}	9.0^{a}	7.9^{b}	7.9^{b}
LSD (5%)	0.40			
CV (%)	2.82			

Means within a column followed by the same letter are not significantly different at (P ≤ 0.05); LSD = least significant difference; CV = coefficient of variation.

3.2.3. Number of Productive Tillers per Plant

The analysis of variance showed that the N and vermicompost fertilizer rates had a significant (P< 0.05) effect on the number of productive tillers (Appendix Table 1 and Table 4). The maximum value (6) was obtained from a combination of 100% of the recommended N with 1.5 t ha^{-1} of vermicompost and also with and 2 t ha^{-1}. The increased number of productive tillers with an increase in N and vermicompost rates could be attributed to the joint role of these fertilizers, resulting in normal vegetative and reproductive growth. This combination increased the productivity of the tillers. The increased number of productive tillers could be attributed to the combined role of N and vermicompost, with N availability initiating cell division and elongation, resulting in normal vegetative and reproductive growth. The combination might have a synergistic impact increasing the number of productive tillers. However, the lowest value (1) was obtained at 0% of N with all rates of vermicompost except at 2 t ha^{-1}. The findings were consistent with those of Ejaz et al. (2002), who found that increasing N application improved the number of productive tillers. Furthermore, Godebo *et al*. (2021) showed that N fertilization greatly enhanced wheat productive tiller per plant.

Table 4: Number of tillers of Bread wheat influenced by the interaction effects of different levels of Nitrogen and Vermicompost

N levels (Kg ha^{-1})	Vermicompost (t ha^{-1}) 0	1	1.5	2
0	1^{g}	1^{g}	1^{g}	2^{gf}
50	2^{edf}	3^{de}	3^{de}	4^{bc}
75	4^{bc}	4^{bc}	4^{bc}	5^{abc}
100	4^{bc}	4^{bc}	6^{a}	6^{a}
LSD (5%)	1.38			
CV (%)	15.38			

3.3. Effect of Combined N and Vermicompost Rate on Yield and Yield Components

3.3.1. Aboveground Biomass Yield

The analysis of variance showed that the interaction effect of N and vermicompost fertilizer highly significantly ($p < 0.01$) influenced the above-ground biomass of bread wheat compared to the control treatment (Appendix Table 1). The highest (4.7 t ha^{-1}) above-ground biomass was recorded in the combined application of 75% of recommended N fertilizer and 2 t ha^{-1} vermicompost followed by the combined application of 100% of recommended N fertilizer with 1.5 vermicompost ha^{-1} (Table 5). The increase in biomass yield compared to the control treatment might be due to readily available nitrogen to the crop from an inorganic source of fertilizer and the mineralization of vermicompost which provides better nutrition and soil physical and biological environment (Amare & Kassaye, 2017).

Table 5: Above-ground biomass yield of bread wheat influenced by the interaction effects of different levels of Nitrogen and Vermicompost

	Aboveground biomass (t ha^{-1})			
	Vermicompost (t ha^{-1})			
N levels (Kg ha^{-1})	0	1	1.5	2
0	2.4^{i}	3.0^{h}	3.2^{gh}	3.5^{g}
50	3.5^{fg}	3.8^{ef}	4.2^{bcd}	4.2^{bcd}
75	3.8^{ef}	3.8^{ef}	4.2^{cde}	4.7^{a}
100	3.9^{de}	4.2^{cde}	4.5^{ab}	4.3^{abc}
LSD (5%)	0.4			
CV (%)	5.5			

Means within a column followed by the same letter are not significantly different at ($P \leq 0.05$); LSD = least significant difference; CV = coefficient of variation.

3.3.2. Grain Yield

The analysis of variance exhibited that the interaction effects of N and vermicompost rates were found to have a significant ($P < 0.05$) influence on the grain yield of wheat (Appendix Table 1). The highest grain yield (2.773 t ha^{-1}) was obtained from the combined application of 75% recommended nitrogen and 2 t ha^{-1} vermicompost rates and the lowest grain yield (1.062 t ha^{-1}) was recorded from the control (Table 6). The result of the study showed that the combined application of vermicompost and inorganic N fertilizer far exceeds the sole application of either vermicompost or inorganic N fertilizer.

The combined application of inorganic N and vermicompost application significantly enhanced grain production of the *Kekeba* variety of bread wheat. These positive interaction effects enhance crop development and yield (Gebisa et al., 2021). The improvement in wheat production with increasing inorganic N and vermicompost rates to sufficient levels could be attributed to N involvement in increasing leaf area and promoting photosynthetic efficiency, which promotes dry matter production and increases yield (Alemu, 2019; Abdela, 2023). Integrating inorganic fertilizers with organic fertilizers could improve the physical, chemical and biological fertility of the soils and minimize environmental effects.

Table 6: Grain yield of bread wheat influenced by the interaction effects of different levels of Nitrogen and Vermicompost

	Grain yield (kg ha^{-1})			
	Vermicompost (t ha^{-1})			
N levels (Kg ha^{-1})	0	1	1.5	2
0	1062.0^{ji}	1357.4^{hij}	1211.7^{ji}	1705.7^{efdh}
50	1491.7^{ghij}	1638.5^{fghi}	1783.7^{defgh}	1963.0^{cdefg}
75	1603.3^{fghi}	1974.1^{cdef}	2264.3^{bc}	2773.2^{a}
100	1977.6^{bcdef}	2250.5^{bcd}	2449.4^{ab}	2166.3^{bcde}
LSD (5%)	475.02			
CV (%)	14.02			

Means within a column followed by the same letter are not significantly different at ($P \leq 0.05$); LSD = least significant difference; CV = coefficient of variation.

As the rates of vermicompost increase the rates of inorganic N fertilizer required for optimum wheat production decreases. Such a finding is very important for low inorganic fertilizer input users and also to minimize the environmental effect of inorganic N fertilizer for high inorganic N fertilizer input users. According to Godebo (2021), vermicompost is a rich source of macro and micronutrients, vitamins, enzymes, growth hormones and microflora, which improves the fertility of topsoil and enhances the productivity of the crop.

4. Conclusion

Crops could be supplied essential nutrients both from inorganic and organic sources. Examining the sole and combined application rates has paramount importance for optimum and sustainable crop production and soil fertility management. The results of the present study showed that the combined application of vermicompost and inorganic N fertilizer greatly enhanced plant height, spike length, aboveground biomass and grain yield of bread wheat variety (*Kekeb)*. The combined application of 2 t ha^{-1} vermicompost and 75 kg of urea ha^{-1} application of fertilizer resulted in the highest grain yield (2.773 t ha^{-1}). As a result, it can be concluded that the combined application of 2 t ha^{-1} vermicompost and 75 kg urea ha^{-1} are recommended for farmers of the study area and similar agro-ecologic settings. This rate can also be used as a starting point for further research in the combined application of vermicompost and N fertilizer for different wheat cultivars.

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Appendix Table 1. Analysis of variance (ANOVA) for mean square values of days to maturity, plant height, number of tiller, and spike length, above ground biomass and grain yield

Source	DF	Days to maturity		Plant height (cm)		Number of productive tiller		Spike length (cm)		Above ground biomass (ton/ha)		Yield (kg/ha)	
		M S	Pr >	M S	Pr >	M S	Pr >	M S	Pr > F	M S	Pr > F	M S	Pr >F
Rep	2	44.2656	0.0307	24.11	0.055	0.15	0.055	0.229	0.016	0.321	0.003	2863084	<.001
N	3	311.576	<.0001	257.68	<.001	29.4	<.001	1.048	<.001	3.543	<.001	1491994	<.001
VC	3	13.5903	0.3254	193.46	<.001	4.81	<.001	1.423	<.001	1.130	<.051	587282	0.003
N*VC	9	77.0319	<.0001	34.39	0.008	7.33	0.008	0.519	<.001	0.217	0.004	379580	0.002
CV		3.24		3.53		15.38		2.82		5.46		14.06	
Mean		112.688		77.74		3.46		7.76		3.83		1854.52	
LSD		6.0		4.50		1.4		0.4		0.4		475.02	

N = Nitrogen, VC = Vermicompost, CV=coefficient of variation, LSD= least significant variation